# GASTROPOD DISTRIBUTION IN THE SHALLOW WATERS AROUND A MOTU OF MOOREA, FRENCH POLYNESIA

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*Abstract.* The gastropod communities around motu Tiahura are currently under various stresses, both natural and anthropogenic. Distribution studies can help understand how these pressures are affecting gastropod communities. The shallow waters around motu Tiahura were partitioned into six distinct habitats. Transects were examined in each habitat to observe gastropod abundance and diversity. Results show that the waters off the conglomerate platform are the most diverse, while the lagoon is least diverse. Three of the habitats were relatively similar in gastropod community, while the other three were distinct. Night transects revealed that burrowing gastropods form a distinct nocturnal community. Differences between gastropod communities may arise from biotic interactions and unique physical factors in each habitat.

*Key words: community composition, assemblage, motu Tiahura, intertidal zone, abundance, diversity, biotic interactions, nocturnal, diurnal, habitat*

## INTRODUCTION

One of the greatest challenges faced by conservationists is the changing nature and 'shifting baselines' of biological communities. In some cases, change is a natural and often necessary component of a habitat. Geological change is continuously occurring, although much of this change occurs over a period spanning millions of years; and some species depend on periodic disturbances such as fire in order to survive. However, unnatural anthropogenic disturbances have exponentially increased in areas around the world, with negative effects on habitat biodiversity (Short & Wyllie-Echeverria, 1996; Charlson, *et al*., 1992; Fahrig, 1997). These man-made disturbances can drastically change the composition of both the physical habitat and the organisms living within it, and habitat fragmentation is the primary cause of local and global extinctions and biodiversity loss across all taxonomic groups (Nichols, *et al*., 2007). Climate change is another anthropogenic threat, although the negative effects it causes on habitats are more subtle. Increased greenhouse gases have caused more heat to be trapped within the atmosphere and have changed climatic patterns (IPCC, 2007). The frequency and intensity of extreme weather conditions such as hurricanes, floods, heat waves, draughts, and tropical cyclones has and will continue to increase (IPCC, 2007). In addition, ocean salinity, surface temperature, and pH balance are shifting (IPCC, 2007; Caldeira & Wickett, 2003). In some tropical areas, climate change may lead to the complete submergence of low-laying islands by raising sea level, and thus severe losses in biodiversity in these areas (Pernetta, 1993).

Due to the variety and intensity of physical changes on habitats, it is important to understand the biological communities within these habitats, and how they change in response to shifting physical factors. Primarily due to accessibility issues, a great deal more research has been dedicated to the understanding and conservation of terrestrial rather than marine environments (Olsgard, *et al*., 2003). It is known, however, that coastal areas harbor a wide variety of habitats that support high species diversity, such as coastal sedimentary habitats (Gray, 1994), intertidal rock walls, and coral reefs (Huston, 1985; Sheppard, 1980). Unfortunately, biodiversity is most threatened in these coastal zones, most usually resulting from anthropogenic affects (Gray, 1997). In order to develop conservation strategies for the protection of biodiversity in these coastal ecosystems, more research on basic marine biodiversity patterns and community structure should be conducted (Olsgard, *et al*., 2003).

Molluscan communities are effective indicators of overall ecosystem health and species diversity (Rittschof & McClellan-Green, 2005), making them ideal study organisms of conservation and biodiversity studies. Gastropods are of particular interest, not only due their importance in human culture but also because they fill integral ecological roles, from grazers to scavengers and carnivores (Sturm, *et al*., 2006). They inhabit a range of diverse habitats, from backyard gardens to the deep sea (Suominen, *et al*., 2003; Rex, 1973; Sturm *et al*., 2006). They are also found in the shallow waters surrounding motus in the South Pacific.

Motus are small islets formed on the barrier reefs of coral reef islands by storm debris from cyclones (Murphy, 1992). They are relatively ephemeral on a geological time span, as they are constantly under the forces of erosion and sand deposition and could easily be modified immensely by intense tropical storms (Murphy, 1992). Because of these factors, motus make interesting study sites. I choose the shallow waters around motu Tiahura, located off the coast of Moorea, French Polynesia, as the site for my distribution study. Since the formation of this motu, human pressures on the area have drastically increased (Augustin, *et al*. 1999, Hutchings *et al*., 1994). Between 1971 and 1996, the human population of the northern and western coasts of Moorea nearly tripled, and hotel capacity increased five-fold (Augustin, *et al*. 1999). These hotels drain waste into the channel between Moorea and motu Tiahura, likely increasing organic pollution (Augustin, *et al*. 1999; Hutchings, *et al*. 1994). In addition, the channel was dredged, causing increased turbidity and sedimentation, which has been documented to have negative effects on epibenthic organisms (Levin, 1970). Several natural disturbances have also recently occurred, including an outbreak of *Acanthaster planci*, major coral bleaching events, and cyclones in 1906 and 1991 (Augustin, *et al*. 1999).

In order to understand how these disturbances are affecting the distribution of marine gastropods, a survey of gastropod communities in the environments around the motu must first be conducted. In this study, I am interested in investigating how communities of marine gastropods differ between the coastal shallow-water habitats of the motu Tiahura, located off the northwestern coast of Moorea. I hypothesize that different habitats will play host to different communities of gastropods, though there will likely be some overlap in species.

## METHODS

### *Study site*

Moorea is a volcanic island located within the Society island chain in French Polynesia, at 149°50′ W and 17°30′ S. Two motus which share a lagoon are located on the barrier reef off the northwestern coast of Moorea. Motu Tiahura is the smaller and westernmost of the two motus, located at 149°54′43 W and 17°29′15 S. I examined eighteen transects across five different coastal habitats around the motu Tiahura, located off the northwestern coast of Mo'orea, French Polynesia. I classified the intertidal and shallow water areas around the motu into six habitat zones. The 'conglomerate platform' zone, off the north coast off the island, is closest to the edge of the barrier reef and thus receives a substantial amount of wave action from the open ocean (Figure 1). The 'sand flats,' is a wide expanse of very shallow water on the depositional sands off the east side of the motu. The 'sheltered sand flats,' is similar to the sand flats, but the habitat is somewhat sheltered from wave action and strong currents by the conglomerate platform, which allows the growth of thick algal mats. The 'coral rubble' zone stretches from the south coast along the west side of the motu, and is characterized by coral rubble pieces scattered on top of the substrate. The 'lagoon' section contains live coral in a sandy substrate and is located around thirty-five meters from the western shore. Lastly, the 'sheltered lagoon' is located on the west side of the island and consists of a relatively flat area littered with

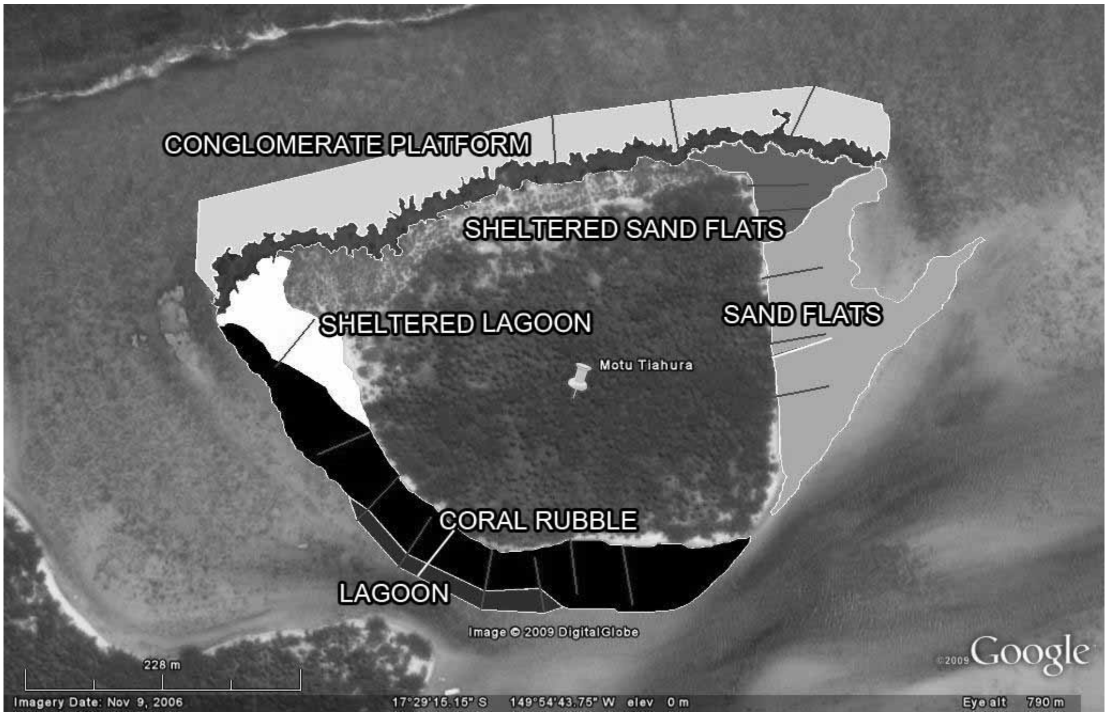


Figure 1. Motu Tiahura, including the 6 habitat zones and transects taken. Normal (daytime) transects are shown in gray, while night transects are shown in white.



large and small pieces of coral rubble. It is also sheltered from some wave action and turbulence by the conglomerate platform. All of these habitats are shown in Figure 1.

I examined three transects in both the sand flats zone and the conglomerate platform zone. Two transects were taken in the sheltered sand flats zone, and one in the sheltered lagoon zone. In addition, I examined four transects off the southern face of the motu, and three more on the western side. Two transects were taken at night: one on the sand flats, and one on the southwestern corner into the lagoon. The data from these transects were later sectioned into the appropriate habitat zones, since in some cases a transect would pass through multiple habitat zones.

*Methods*

I recorded my data over a period of few weeks (Sept. 24th, 2009 – Nov. 14, 2009). I took fifty meter continuous transects perpendicular to shore, starting from the high tide line. The width of each transect was 50 cm, measured by a 50cm x 50cm quadrat of PVC pipe that I shifted along the length of the transect. I searched the surface of the substrate, as well as the underside and crevices of coral rubble, but did not sift through sediment. When I sighted a gastropod greater than 1cm long from the anterior to the posterior, I identified it, and recorded the species as well as the distance along the transect at which it was found. If I could not identify the gastropod in the field, I collected it and took it back to the lab at Gump Field Station for identification using *Shells of Tahiti* (Salvat, *et al.*, 1984), *Coquillages de Polynésie* (Salvat & Rives, 1986) or the help of Gustov Paulay, of the Moorea Biocode Project.

I took GPS coordinates at the start and end of each transect. In the few cases in which I could not bring a GPS device to the end of the transect, I recorded a midpoint along the transect and later extrapolated the end point from that line. I created that map shown previously by importing the GPS points for each transect were into Google Earth Pro.

*Statistical Analysis*

I determined richness (total species in a community) and calculated diversity (which takes into account both species richness and abundance) for each habitat. I measured habitat diversity using both Simpson's and Shannon's diversity index. I used Whittaker's measure of β diversity to calculate similarity between habitats. I used the stats program JMP to create a discriminate analysis graph which was used to visually show how species (and their absolute abundances) contributed to the differentiation between the gastropod communities of different habitats. I created the graphs showing abundance data by using Microsoft Excel.

## RESULTS

In total, the samples included 43 species of gastropods from 14 families. Of these, 39 species from 12 families were included in the abundance analyses for the habitats, as four of the species sampled were found exclusively at night and are included only in the nocturnal and diurnal community assemblage comparison. The total abundance of each species and its contribution from each habitat is shown in Figure 2.

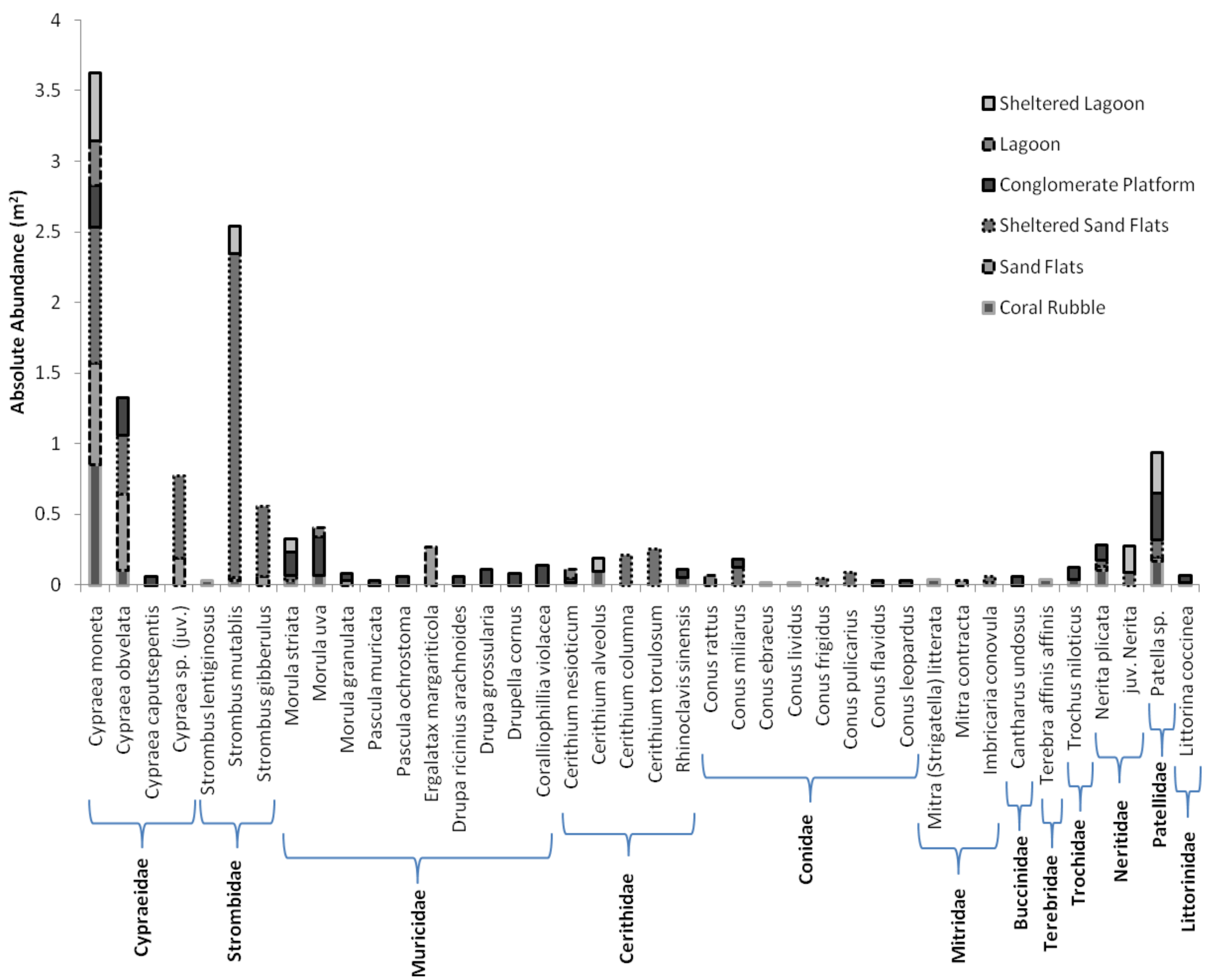


Figure 2. The total (absolute) abundance across all habitats is shown for each species, further divided into the contribution from each habitat (shown by different shading). Species are grouped taxonomically.

The gastropod community assemblage of each habitat was analyzed in several ways. The conglomerate platform claimed the greatest species richness and diversity, while the lagoon habitat was both least rich and least diverse (Table 1).

Table 1. Richness and diversity by habitat. In this case, richness and diversity ranking coincided for every habitat.

| Habitat | Species Richness | Simpson's Diversity | Shannon's Diversity |
|---|---|---|---|
| Coral Rubble | 18 | 0.727 | 3.109 |
| Sand Flats | 10 | 0.755 | 2.264 |
| Sheltered Sand Flats | 15 | 0.794 | 2.737 |
| Conglomerate Platform | 22 | 0.932 | 5.400 |
| Lagoon | 4 | 0.643 | 2.011 |
| Sheltered Lagoon | 6 | 0.835 | 2.702 |

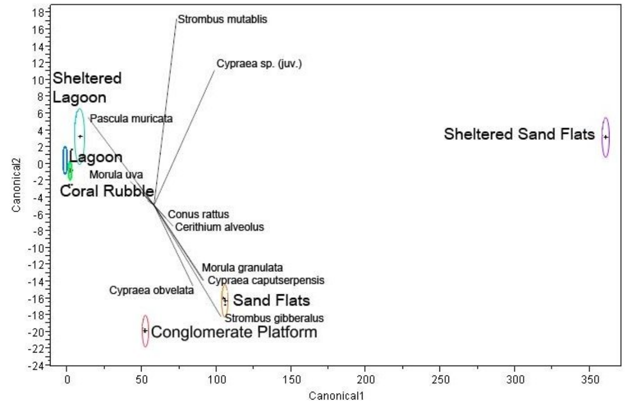


Figure 3. Discriminant analysis showing how the habitats differ based on the absolute abundances of each species. The more important species in differentiating the groups are shown as longer lines, with less significant species not shown. The colored ovals represent habitats; the further apart they are from one another, the more distinct the habitats are in respect to abundance of different species. Using this analysis, Sheltered Lagoon, Lagoon, and Coral Rubble are shown to be relatively similar to each other, while Conglomerate Platform, Sand Flats, and especially Sheltered Sand Flats are very distinct in gastropod community assemblages.

To compare gastropod community similarity between habitats, two approaches were used. Firstly, Whittaker's measure of β diversity was used to compare the gastropod community species composition between the habitats (Table 3).

However, Whittaker's measure can only analyze two habitats at a time, and does not take species abundance into account. To rectify this, a discriminate analysis was performed on the habitats, using species absolute abundance (per m$^2$) as the variables which discriminate among habitats (Figure 3). The discriminate analysis reveals four major groupings of gastropod communities. Sheltered sand flats, sand flats, and the conglomerate platform were shown to be fairly distinct from each other and from the rest of the habitats. Lagoon, Coral Rubble, and Sheltered Lagoon were grouped similarly, though shown to differ from the remaining three groups in community composition.

Table 2. Whittaker's measure of β diversity uses the presence/absence of species between two sites, and the overlapping species between the two. Higher values indicate more similarity.

| Habitat | Sand Flats | Sheltered Sand Flats | Conglomerate Platform | Lagoon | Sheltered Lagoon |
|---|---|---|---|---|---|
| Coral Rubble | 0.214 | 0.424 | 0.500 | 0.273 | 0.417 |
| Sand Flats | - | 0.400 | 0.188 | 0.143 | 0.250 |
| Sheltered Sand Flats | - | - | 0.270 | 0.105 | 0.381 |
| Conglomerate Platform | - | - | - | 0.231 | 0.143 |
| Lagoon (live coral) | - | - | - | - | 0.200 |

The species composition and abundance data from each night transect was compared to the data from a nearby transect that was taken during the day (Figure 4). In the coral rubble habitat, the species richness for the community is constant, although the species makeup is nearly entirely different. In the sand flats, the nocturnal community is much more diverse than that found during the day. In both habitats, only a few species were found in both the night and the day transects. Four species were found exclusively at night: *Mitra mitra*, *Pyramidella maculosa*, *Rissonia ambigua*, and *Conus coronatus*. Of these, three were found in the sand flats (*M. mitra*, *P. maculosa*, and *R. ambigua*) and two were found in the coral rubble transect (*M. mitra* and *C. coronatus*). Much of the nocturnal gastropod community in both habitats consisted of species from the carnivorous *Conidae* and *Mitridae* families.

## DISCUSSION

The fact that the sand flats, sheltered sand flats, and conglomerate platform habitats were markedly different from each other and the other three habitats (coral rubble, lagoon and sheltered lagoon) can be attributed to a variety of different factors. The northern coast and the western coast are fairly isolated from each other and from the south/east coasts, either by the conglomerate platform or the deep channel on the southern coast. However, the southern and eastern coasts are not isolated from each other. Since all three of the similar habitats were found on the southern and/or eastern side of the island, their similarity may rise to some extent from proximity to each other and the lack of major barriers between habitat types. More importantly, however, each habitat had physical factors that may have influenced the

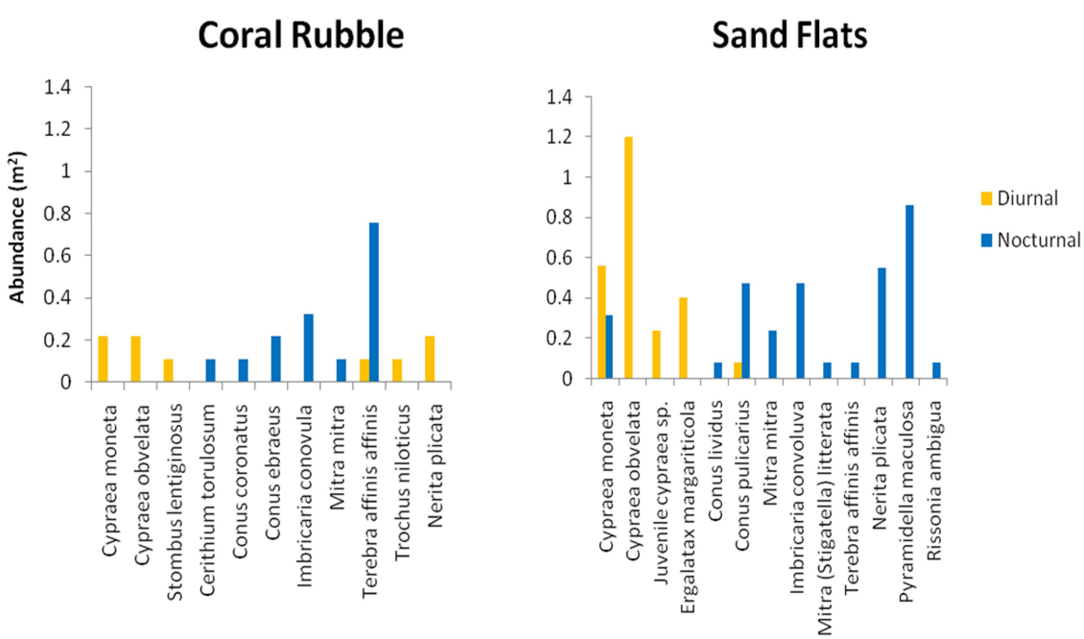


Figure 4. Comparisons of night and day transects from both habitats. Absolute abundance of gastropods (per $m^2$) is shown for each habitat, further divided into night and day. Only a few species were found both at night and during the day.

species within it.

The abundance of gastropods in the conglomerate platform habitat is not necessarily greater than the other habitats, but the richness is, making the habitat highly diverse. Although the conglomerate platform habitat was subject to a substantial amount of wave action and turbulence from the open ocean, biotic interactions with other marine invertebrates allowed gastropod diversity to flourish. Coral reef habitats are among the most diverse in the world (Bellwood & Hughes, 2001), and are often host to species with very specific niches (Knowlton & Jackson 1994). The waters off the conglomerate platform are habitat for a significant amount of relatively healthy live coral, and are home to many gastropods not found in the other habitats. Much of the species richness (40%) of the conglomerate platform came from predatory snails of the *Muricidae* family, including corallivores such as *Drupella cornus* and *Coralliophillia violacea*.

On the other hand, the lagoon habitat, though it was also a habitat for live coral, had the lowest richness and diversity of all six habitats. One possible reason may be human harvesting. The area is a popular destination for tourists from the northwest side of the island (Augustin, *et al*. 1999). As a result, obvious or colorful seashells may be harvested extensively as souvenirs, decreasing the population of those species in the lagoon. The coral in the lagoon was also less dense than that of the conglomerate platform, so the chance of seeing coral-dwelling species was less in the lagoon. Of course, the low area sampled in the lagoon was likely the most significant factor influencing the low species diversity, and is discussed later in the paper.

Although there are no physical barriers between the sand flats and the sheltered sand flats, the gastropod communities are strikingly different. Whittaker's measure of β diversity indicates fairly high similarity between the two habitats, due to the relative similarity of species composition. However, the sand flats gastropod community is radically different once abundance is taken into account (Figure 3). The very high abundance of *Strombus mutablis* in the sheltered sand flats, and its rarity in other habitats, differentiates the sheltered sand flats from the other zones (Figure 2). It is considered a strong factor in the discriminant analysis, as shown by the length of its corresponding line in Figure 3. Like the conglomerate platform habitat, this community may also be linked to other biota. *Strombus mutablis* were found mainly atop the algal mats that grew extensively in the sheltered sand flats, likely due to the reduced current and wave action provided by the conglomerate platform. I also did not find many gastropods underneath the algal mats, which may suggest that the algae have an inhibitory effect on some of the snails that were found in the sand flats. If so, this effect would account for some of the discrepancy in community composition between the two sites.

The three most similar habitats were moderately but not strongly correlated by Whittaker's measure of β diversity. Of the three, sheltered lagoon and coral rubble were most strongly correlated. The similar species composition may be due to similar substrate and proximity, since the substrate for both habitats was littered with coral rubble and the habitats were bordering one another. Previous studies have shown that substrate architecture is important in gastropod distribution (Kershner & Lodge, 1990). Sheltered lagoon and sheltered sand flats also had a fairly strong correlation in community makeup. It's probable that the reduction of wave action and turbulence afforded by the conglomerate platform in both 'sheltered' habitats allowed for similar gastropod communities. However, the absence of high densities of *Strombus mutablis* in the sheltered lagoon was enough to strongly differentiate the two habitats in the discriminate analysis.

In both the sand flats and in coral rubble, the nocturnal gastropod community surveyed differed almost completely with its corresponding diurnal community. Species found both in both nocturnal and diurnal transects for a habitat were rare, and most were found in far greater abundances in either the diurnal or the nocturnal transect. All but two species found at night had conical, streamlined shells, which is morphology indicative of burrowing snails (Trueman & Brown, 1989). Burrowing could also explain why these nocturnal snails were rarely found during the day. The *Mitridae* and *Conidae* families, both families of nocturnal, burrowing, carnivorous gastropods, were featured prominently in both nocturnal transects. These results are in keeping with previous studies, which suggest that *Conidae* snails are more diverse in areas of predominantly sand, coral rubble, and algae (Laczek-Johnson, 1994). Although the species found in the nocturnal transects were not factored into the habitat comparison, these nocturnal studies reveal another dimension to the gastropod community.

I did face a few problems with my study. As with most distribution studies, the amount of species found is dependent on the skill, awareness, and thoroughness of the observer. I may have unknowingly overlooked some gastropods. Additionally, as mentioned before, I only recorded gastropods on the surface of the substrate or on rubble or rock. The results of my night transects indicate that this method of sampling obscures a large portion of the gastropod community, specifically burrowing gastropods. In order to fully understand gastropod communities in each habitat, more night transects or sampling that involved sifting through the sediment would be necessary. Another fairly major source of error rises from the unevenness of sample sizes across habitats. Initially, I divided my habitat zones by direction (north, south, west, and two eastern habitats, sand flats and sheltered sand flats). However, I later determined more partitioning was necessary due to significant differences in physical habitat within these zones. I divided up the habitats and corresponding transects into the six habitats I now use in the study, however, some habitats now have significantly more area sampled than others. Since richness increases with total area sampled (Cain, 1938), my richness and diversity data is skewed, and far from ideal. This is not to say that my data cannot be useful, however.

One of the qualities of a distribution study is its potential use in future research. A natural progression of my study would be a distribution study around motu Fareone, the partner motu of Tiahura which shares the lagoon. It would be interesting, and reaffirming, to observe the same patterns of gastropod distribution there, and if the distribution is unexpected the factors that contribute to the differences could be researched. Secondly, more niche partitioning studies could be partaken using my data to observe if my habitat zones are a factor in determining the relative abundance between two different species of gastropods. More abiotic and biotic factors could be analyzed for a more comprehensive study. Thirdly, a study on hermit crab distribution could be complementary to my study. Comparing hermit crab distribution (and what shells they occupy) to gastropod distribution could potentially yield results showing hermit crab migration, hermit crab nursery habitats, or how long a hermit crab keeps a shell. This project could easily be partnered with a lab component for a comprehensive study.

Of course, distribution studies are often extensively used for resurvey or long-term distribution projects. Human pressures on the motu have been increasing, and will continue to increase; and another severe natural disturbance such as another *Acanthaster planci* infestation could occur on short notice. The geomorphology of the motu is also slowly changing, and could be altered significantly in a short time period should another cyclone cross its path. I have measured distribution at one moment in time; in the future, a similar distribution study should be partaken to show how these gastropod communities are shifting. The world is a changing place, now more than ever. Long-term distribution studies can show how that change is occurring, and help us to conserve the biological diversity of the planet.

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